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AGE AND GROWTH OF RED HIND AND ROCK HIND COLLECTED FROM NORTH CAROLINA THROUGH THE DRY TORTUGAS, FLORIDA

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ABSTRACT

Opaque bands on sectioned sagittal otoliths were used to age red hind, *Epinephelus guttatus* (N = 146), and rock hind, *E. adscensionis* (N = 144), sampled from the recreational headboat fishery between North Carolina and the Dry Tortugas, Florida, 1980–1992. Marginal increment analysis revealed that annuli form from March through May for red hind, and April and May for rock hind. The maximum age estimated for red hind was 11 years, compared with 12 years for rock hind. Mean back-calculated total lengths (in mm) at ages 1, 5, and 10 were similar for both species: 228-, 358-, and 436-mm for red hind; and 214-, 362-, and 441-mm for rock hind. The von Bertalanffy growth equations for red hind and rock hind were $L_t = 471.4(1 - e^{-0.200(t+2.397)})$, and $L_t = 499.4(1 - e^{-0.167(t+2.495)})$, respectively, where t = age in years. The length-weight relationship for red hind was $W = 1.8 \times 10^{-7}L^{2.614}$, where W = weight in kilograms, and was $W = 6 \times 10^{-9}L^{3.193}$ for rock hind. Age-length keys are provided for each species. Red and rock hinds appear to grow faster and do not live as long as many serranids from the southeastern United States.

The red hind, *Epinephelus guttatus,* and rock hind, *E. adscensionis,* are moderate-sized, speckled groupers (Serranidae, Epinephilinae). They inhabit coral reefs and rocky substrates in tropical and subtropical waters to depths of 122 m from North Carolina to Brazil, including the Gulf of Mexico and the Caribbean. Both are abundant off Bermuda and in the West Indies (Manooch, 1984; Fischer, 1978), and are relatively uncommon along the southeastern United States north of Florida. Species distinction may be made based upon coloration. Red hind have pale pink bodies with uniform red spots, and the soft-rayed portions of the dorsal and anal fins as well as the caudal are margined in black. Rock hind have tawny brown bodies and fins covered with reddish brown spots, and two or three dark blotches at the base of the dorsal fin and caudal peduncle (Fischer, 1978).

Both groupers have been captured throughout their ranges by commercial fishermen using hook and line and baited traps, and occasionally by beach seines and trawls. Recreational fishermen catch the species while bottom fishing with cut bait (Manooch, 1984). Most catches are taken off Bermuda, the Bahamas, and throughout the West Indies where red hind are more prevalent in landings than rock hind.[1] Off the southeastern United States, landings are infrequent relative to other grouper. Commercial landings from the Carolinas, and Georgia identify the two species, whereas in Florida statistics they are listed under "unclassified grouper." Among states that made species distinctions, North Carolina reported the greatest landings of red hind—approximately 4.8 t in 1987, 5.0 t in 1989, and over 10.8 t in 1990.[2] These weights represent less than 10% of the total grouper landings. Catches of rock hind are uncommon in the area, and recreational landings of red hind are centered in Florida where landings between 1979–1989 ranged from 2.0 t–7.0 t (Van Voorhees et al., 1992).

Most life history information on the red hind and rock hind comes from the

[1] Yvonne Sadovy, pers. comm., Hui Oi Chow Science Building, University of Hong Kong, Pokfulam Road, Hong Kong. Brian Luckhurst, pers. comm., Division of Fisheries, Dept. of Agriculture, Fisheries and Parks, P.O. Box CR52, Crawl CR BX, Bermuda.

[2] Guy Davenport, pers. comm., Southeast Fisheries Science Center, National Marine Fisheries, 75 Virginia Beach Drive, Miami, Florida 33149.

Caribbean. Colin et al. (1987) discussed the spawning behavior of red hind off Puerto Rico; Thompson and Munro (1983) reported on the distribution, spawning, growth, and mortality of red hind from Brazil; Nagelkerken (1981) studied the distribution of red hind in the Netherlands Antilles; Thompson and Munro (1978) included the red hind in their discussion of the biology and ecology of reef fishes in the Caribbean; Olsen and LaPlace (1978) presented fecundity, size, sex ratio, and length-weight data for red hind from the Virgin Islands; Burnett-Herkes (1975) reported on the biology and fisheries of red hind in Bermuda with comparative data from the Bahamas and the West Indies; Sadovy et al. (1992) discussed age and growth of red hind from the U.S. Virgin Islands and Puerto Rico; and Luckhurst et al. (1992) recorded an unusually large red hind from Bermuda. Sadovy et al. (1992) were the only researchers who validated aging techniques for red hind. Research on rock hind is limited to notes which occur in several of the references cited above, and in Nagelkerken (1979) who studied their distribution and diet in Curacao and Bonaire, Netherlands Antilles.

We studied the red and rock hinds because age and growth studies have not been conducted on these species along the southeastern United States, and because the two serranids are components of the assemblage of reef fishes currently being managed by the South Atlantic Fishery Management Council. Our objectives were to evaluate sectioned sagittal otoliths for aging red hind and rock hind, determine lengths at specific ages, derive theoretical growth parameters, construct fish age-length keys, and obtain length-weight relationships for each species.

Materials and Methods

Collection, Preparation, and Examination of Otoliths.—Otoliths were collected from 154 red hind and 174 rock hind sampled from headboats (Huntsman, 1976) operating from North Carolina to the Dry Tortugas, Florida, 1980–1992. Total lengths (TL) were recorded in millimeters and weights in kilograms. Sagittal otoliths were collected and stored dry in uniquely labeled coin envelopes. Some otoliths were examined whole; all were examined after they had been sectioned. To identify where erosion of the otolith edge was minimal, whole otoliths were placed in a blackened-bottom watch glass with clove oil and were viewed under a dissecting microscope at 12× using reflected light. All otoliths were then aligned on paper tabs with Crystalbond,[3] mounted in a chuck to prevent lateral movement and sectioned through the focus with a Buehler Isomet 11-180 low-speed saw.[3] Three transverse (0.19–0.21 mm) cross-sections were mounted on glass slides with Crystalbond, clove oil was applied to the sections by pipette and they were viewed under a dissecting microscope at 12×. Reflected light revealed two distinct types of bands, an opaque band that appeared white and a translucent or hyaline band that was dark. Before validation, opaque bands were assumed to be annuli. Shown in Figure 1 using the left half of the section, incremental measurements were taken laterally from the core (focus) to the left edge of the opaque bands and a total radius to the otolith edge.

Validation.—Marginal increment analysis was used to determine if opaque bands on sectioned otoliths were true annuli. The evaluation involved plotting the monthly mean distances of the last opaque band to the otolith margin for various age groups. If the bands were annual, then each plot should reveal a minimum ring-to-margin increment for a period followed by increased increment, indicative of additional growth following annulus formation. We also identified the months where marginal increments equaled zero. This would reveal the month(s) when annuli were formed.

Back-calculated Growth.—Lengths at age (number of opaque bands) for all collecting years were back-calculated from a fish length-otolith radius regression which was derived by regressing fish length on magnified otolith radius (R): $L = a + b(R)$ where L = total length in mm. To calculate size at each age, the means of the distances from the core to each ring were substituted for otolith radius (R in the above equation).

Theoretical Growth.—Calculation of a theoretical growth curve is useful for modeling growth in natural fish populations. Growth parameters such as theoretical mean asymptotic length (L_∞), growth coefficient (K), and theoretical time of the beginning of growth (t_0), may be used in constructing

[3] Mention of products does not mean an endorsement by the NMFS, NOAA.

Figure 1. Photographs of sections from otoliths. upper, Red hind section with 6 rings. lower, Rock hind section with 12 rings.

population models. The most widely used population theoretical growth curve, the von Bertalanffy equation $L_t = L_\infty (1 - e^{-K(t-t_0)})$, was fitted to back-calculated length-at-age data (Ricker, 1975; Everhart et al., 1975). This particular equation allowed us to make comparisons with growth results obtained for other serranids.

Theoretical growth parameters were derived using SAS PROC NLIN with the Marquardt Option (SAS Institute, 1982) and weighted the analyses by the number of fish sampled at each age. The

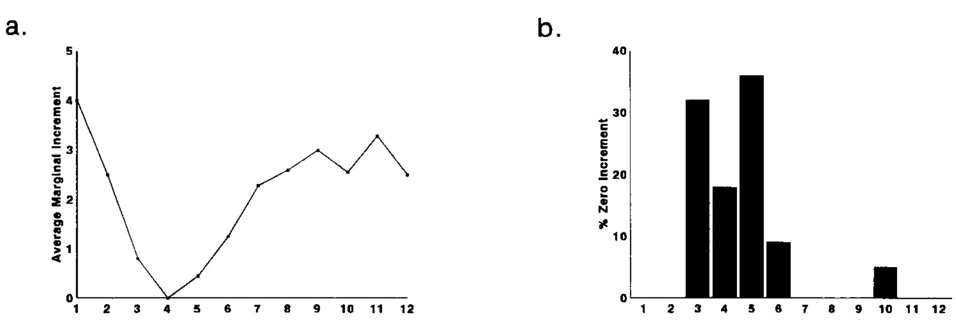

Figure 2. Red Hind a. Average distance of last annulus to margin for all otoliths by month using fish ages 2, 3, and 4. b. The percentage of all otoliths with zero marginal increment plotted by month.

Table 1. Size-at-capture and back-calculated total lengths (mm) at ages for red hind

Age (yr)	Size-at-capture ± 1 SD	N	Annulus 1	2	3	4	5	6	7	8	9	10	11
1	244.0	1	230.5										
2	294.5 ± 16.4	19	233.9	287.5									
3	321.7 ± 26.6	20	228.9	278.6	311.9								
4	354.8 ± 19.4	29	226.9	278.1	312.4	337.0							
5	367.6 ± 25.0	25	226.0	272.9	305.9	332.5	351.7						
6	380.1 ± 32.7	16	227.0	274.1	309.2	337.8	360.8	378.4					
7	395.6 ± 15.5	11	226.1	277.9	312.1	338.4	358.8	374.8	389.4				
8	434.8 ± 12.4	3	230.5	284.0	318.7	348.1	372.2	388.2	401.5	412.3			
9	440.5 ± 26.5	4	220.5	270.6	310.7	340.8	368.9	386.9	402.9	416.9	428.9		
10	487.5 ± 7.7	2	226.5	278.6	322.7	354.8	378.8	398.9	414.9	422.9	431.0	439.0	
11	491.0	1	238.5	286.6	318.7	334.7	350.8	366.8	382.9	398.8	414.9	431.0	447.0
Total		131											
Weighted mean ± 1 SE			228.0	278.0	310.7	337.0	358.3	379.8	395.8	414.9	427.5	436.3	447.0
			±0.9	±0.9	±1.2	±1.4	±1.9	±2.1	±3.3	±3.8	±4.2	±5.3	—
Annual increment			228.0	50.0	32.7	26.3	21.3	21.5	16.0	19.1	12.6	8.8	10.7

Table 2. Lengths at age for red hind

	Observed			Back-calculated			Theoretical		
		Sadovy et al. (1992)			Sadovy et al. (1992)			Sadovy et al. (1992)	
Age (yr)	This study TL (mm)	Puerto Rico FL (mm)	St. Thomas FL (mm)	This study TL (mm)	Puerto Rico FL (mm)	St. Thomas FL (mm)	This study* TL (mm)	Puerto Rico† FL (mm)	St. Thomas‡ FL (mm)
1	244	184	249	228	164	194	232	169	199
2	294	247	260	278	206	228	276	203	226
3	322	256	280	311	236	256	311	233	251
4	355	272	284	337	262	279	340	260	275
5	358	305	319	358	286	301	364	284	297
6	380	321	335	380	305	318	384	307	318
7	396	342	348	396	326	335	399	327	337
8	435	353	362	415	342	349	412	345	355
9	441	374	370	428	359	362	423	361	372
10	487	393	356	436	375	377	432	376	388
11	491	413	391	447	390	400	439	389	402
12		416	424		401	423		401	417
13		422	460		412	438		412	428
14		448	442		426	445		422	440
15		—	492		429	469		431	451
16		448	—		439	460		439	461
17		458	—		448	465		446	471
18			475			470			480

Von Bertalanffy Growth Parameters and Length–Weight Equations:
* $L_t = 471.4(1 - e^{-0.200(t+2.397)})$, $W = 1.8 \times 10^{-7} L^{2.614}$ (W = weight (kg) and L = total length (mm)).
† $L_t = 514.5(1 - e^{-0.1013(t+2.944)})$, $\text{Log } W = -5.21 + 3.1422 \text{Log } L$ (W = weight (g) and L = fork length (mm)).
‡ $L_t = 601.0(1 - e^{-0.0705(t+4.690)})$, $\text{Log } W = -4.68 + 2.9402 \text{Log } L$ (W = weight (g) and L = fork length (mm)).
NB. The caudal fin of this species is convex, therefore FL and TL are essentially the same.

advantages of the non-linear curve-fitting approach are that the procedures are completely reproducible and estimates of the variance associated with parameter estimates are available for testing differences in growth curves. Additionally, back-calculated lengths at every year of life from each fish are used in the regressions.

Length–weight Relationship.—We used the ln–ln regression and transformed the equation to: $W = aL^b$, where W = weight in kg and L = total length in mm, was derived for each species.

Fish Age-Fish Length Keys.—Observed ages at lengths were used to derive a fish age-length key for each species. Fish were aged and assigned to 25-mm length intervals. Age distribution (as percent) was then identified for each size interval.

Results and Discussion

Red Hind.—Cross-sections of red hind otoliths were more legible than whole otoliths. Opaque bands were identified and counted on 97.3% (146 of 150) of the sections examined (Fig. 1a). The oldest fish aged was estimated to be age 11 years old (491 mm TL). Approximately 87% (131 of 150) of the sections examined were distinct enough for core to successive band measurements and back-calculations to be made. Sadovy et al. (1992) sectioned 490 of 501 red hind otolith samples from St. Thomas, U.S. Virgin Islands, but only 162 (33%) were judged to be legible. They found red hind as old as 17 years off Puerto Rico and 18 years off St. Thomas. The largest fish was 504 mm FL.

Validation of opaque bands as annuli is an essential part of any age and growth study, but is especially important when the species occurs in tropical or subtropical regions where the formation of annuli as a result of temperature variation does not necessarily occur. Marginal increment analysis of red hind sagittae with 2, 3, or 4 rings revealed that the mean widths of translucent margins (distance from the outer-most opaque band to the otolith edge) were minimal from March through May (Fig. 2a). We also identified those months when zero marginal in-

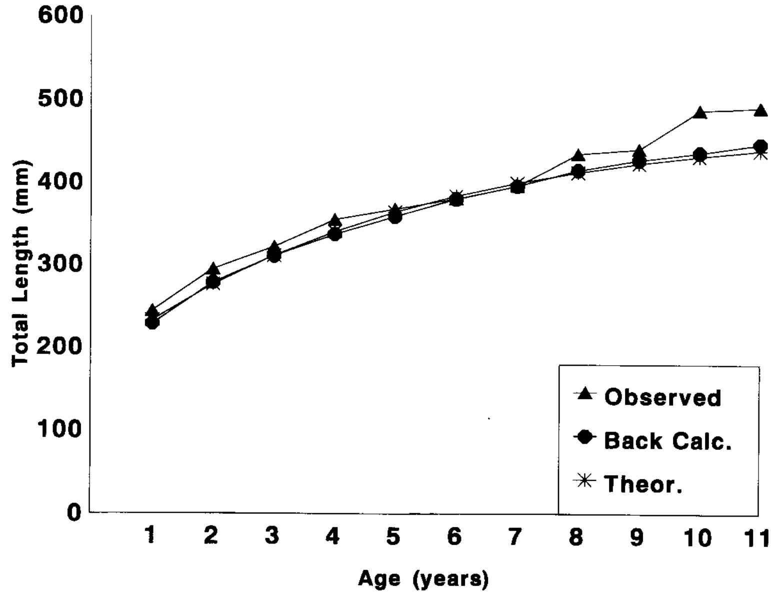

Figure 3. The observed, back-calculated, and theoretical lengths at age for red hind.

crement occurred for all fish. Approximately 86% of zero marginal increment measurements were recorded in March, April and May; 95% for March through June (Fig. 2b). Since both analyses indicated that opaque band formation occurred during spring, we assumed it to be an annual occurrence, thus we considered bands as counted to be annuli. Sadovy et al. (1992) also documented the seasonal formation of opaque bands on red hind otoliths. Marginal increment analysis and a field study involving fish injected with oxytetracycline-OTC-hydrochloride indicated that the II–V annuli begin to form between April and May, and annuli VI–X form between May and July.

Otolith sections from 131 red hind were used to back-calculate fish length at the time of annulus formation (Table 1). The equation: L = 78.205 + 8.017R (N = 140; r = 0.829) was used to determine the relationship between fish length and otolith radius. We found that annual growth was most rapid through age 2, 228 and 50 mm, respectively, then it gradually decreased, 33 to 11 mm, for ages 3 through 11 (Table 1). Our mean back-calculated total lengths for red hind ranged from 228 mm for age 1 to 447 mm TL for age 11. Relatively few fish (N = 7) were older than age 8 (Table 1). Sadovy et al. (1992) reported mean back-calculated sizes at ages ranging from 194 mm FL at age 1 to 470 mm FL at age 18 for fish sampled off St. Thomas and 164 mm FL for age 1 to 448 mm FL for age 17 fish collected off Puerto Rico (Table 2). (For this species TL and FL are essentially the same due to the convexity of the caudal fin.) Growth for fish from both areas was most rapid during the first year of life, and then drastically declined for the second year (34–42 mm).

All back-calculated size at age data (ages 1–11), weighted by the inverse of the number of fish at each age, were used to derive the theoretical growth equation:

$$L_t = 471.4(1 - e^{-0.200(t+2.397)}) \quad \text{(Fig. 3)}$$

Our estimates of red hind growth parameters (L_{oo}, K, and t_o) are compared to

Table 3. Fish age–fish length key for red hind

Length class (25 mm)	Age											
	1	2	3	4	5	6	7	8	9	10	11	Total
225	1 (100.00)											1
250		1 (50.00)	1 (50.00)									2
275		11 (78.57)	3 (21.43)									14
300		7 (43.75)	5 (31.25)	2 (12.50)	1 (6.25)	1 (6.25)						16
325			10 (32.26)	11 (35.48)	7 (22.58)	3 (9.68)						31
350			2 (7.14)	15 (53.57)	8 (28.57)	3 (10.71)						28
375			1 (3.70)	5 (18.52)	10 (37.04)	2 (7.41)	9 (33.33)					27
400					3 (17.65)	9 (52.94)	3 (17.65)	1 (5.88)	1 (5.88)			17
425							1 (20.00)	3 (60.00)	1 (20.00)			5
450									2 (100.00)			2
475										2 (66.67)	1 (33.33)	3
Total	1	19	22	33	29	18	13	4	4	2	1	146

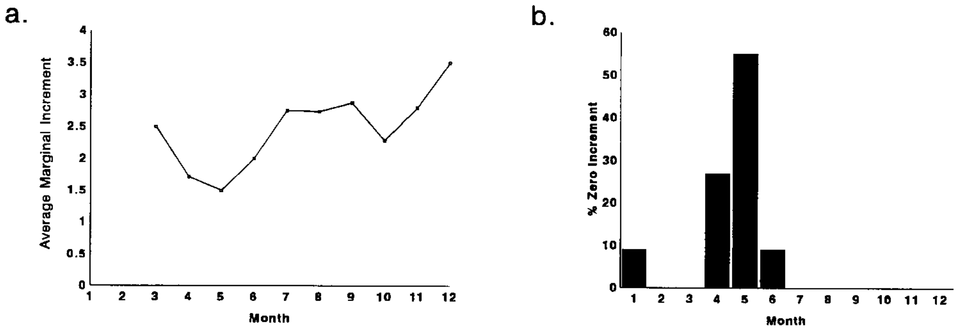

Figure 4. Rock Hind a. Average distance of last otolith to margin for all otoliths by month using fish ages 2, 3, and 4. b. The percentage of all otoliths with zero marginal increment plotted by month.

other studies (Table 2). Red hind from the southeastern United States are shorter-lived and faster growing than those from Bermuda, Jamaica, the Virgin Islands or Puerto Rico (Burnett-Herkes, 1975; Sadovy et al., 1992).

All red hind samples (N = 96) that had both weight and length data recorded (244 mm–491 mm TL and 0.228 kg–1.100 kg whole weight) were used to develope the relationship between length and weight and was represented by the equation $W = 1.8 \times 10^{-7}L^{2.614}$ (N = 96; $r = 0.875$).

The red hind age-length key is included in Table 3.

Rock Hind.—Opaque bands were identified and counted on 85.7% (144 of 168) of the samples, and measurements used to back-calculate lengths at ages were made on 85.4% of the legible ones (123 of 144). Sectioned otoliths of rock hind were very similar to red hind in structure and legibility (Fig. 1b).

Marginal increment analysis for rock hind sagittae with 2, 3, and 4 opaque bands indicated that they were true annuli and were formed primarily in April and May (Fig. 4a). Inspection of data for all otoliths revealing zero growth increment confirms this observation: 82% zero increments occurred in April and May; 91% in April, May, and June (Fig. 4b).

Otolith radial measurements from cross-sections (core to otolith margin) from 134 rock hind were used to calculate the equation for the relationship between total length and otolith radius: $L = 74.868 + 9.334R$ ($r = 0.89$). Mean back-calculated lengths were 214-mm, 362-mm, 441-mm, and 467-mm TL for fish estimated to be ages 1, 5, 10, and 12, respectively (Table 4). Growth was most rapid for the first two years, then slowed with increasing age.

Back-calculated size at age data were used to calculate the theoretical growth equation:

$$L_t = 499.4(1 - e^{-0.167(t+2.495)}).$$

Observed, back-calculated, and theoretical size at age are presented in Table 4 and Figure 5.

All rock hind samples (N = 109) with both weight and length data recorded (233 mm–490 mm TL and 0.222 kg–2.400 kg whole weight) were used to show the relationship between length and weight and was $W = 6 \times 10^{-9}L^{3.193}$.

The rock hind age-length key is included in Table 5.

Management Implications.—The contribution of red and rock hind to commercial and recreational fisheries along the southeastern United States is minor compared to some groupers. Nevertheless, they are inextricably-linked components of the

Table 4. Size-at-capture, back-calculated and theoretical total lengths (mm) at ages for rock hind

Age (yr)	Size-at-capture ± 1 SD	N	Annulus 1	2	3	4	5	6	7	8	9	10	11	12
1	—	0												
2	281.0 ± 21.2	18	206.1	268.3										
3	325.9 ± 22.9	29	215.8	270.9	308.9									
4	354.7 ± 19.9	24	214.5	269.7	305.5	334.3								
5	381.9 ± 14.7	22	210.6	268.3	306.5	334.1	360.8							
6	405.4 ± 13.0	12	218.0	279.4	314.4	338.6	360.3	376.7						
7	424.6 ± 12.7	7	221.5	280.2	314.9	345.6	366.9	388.2	405.6					
8	443.4 ± 14.3	4	217.2	280.2	319.9	345.6	361.9	375.9	392.2	408.6				
9	446.0 ± 17.9	3	224.2	274.0	308.2	342.4	367.3	389.1	414.0	426.4	435.8			
10	457.7 ± 24.0	2	205.5	266.2	298.9	326.9	354.9	373.6	392.2	410.9	429.6	443.6		
11	490.0	1	214.9	289.6	326.9	354.9	373.6	392.2	410.9	429.6	438.9	448.2	457.6	
12	490.0	1	214.9	252.2	280.2	298.9	336.2	354.9	373.6	392.2	410.9	429.6	448.2	466.9
Total		123												
Weighted mean			213.8	271.5	308.8	336.5	361.5	380.1	401.0	414.3	430.9	441.2	452.9	466.9
± 1 SE			±0.9	±1.3	±1.6	±2.0	±2.1	±3.0	±4.2	±5.7	±7.7	±7.0	±4.7	—
Annual increment			213.8	57.7	37.3	27.7	25.0	18.6	20.9	13.2	16.6	10.3	11.7	14.0
Theoretical (weighted)			220.8	263.7	299.9	330.6	356.6	378.5	397.1	412.9	426.2	437.4	447.0	455.0

Table 5. Fish age—fish length key for rock hind

Length class (25 mm)	Age 2	3	4	5	6	7	8	9	10	11	12	Total
225	1 (100.00)											1
250	5 (100.00)											5
275	11 (61.11)	6 (33.33)	1 (5.56)									18
300	1 (11.11)	8 (88.89)										9
325	1 (4.55)	12 (54.55)	9 (40.91)									22
350		6 (19.35)	16 (51.61)	9 (29.03)								31
375			4 (17.39)	16 (69.57)	3 (13.04)							23
400				2 (12.50)	9 (56.25)	5 (31.25)						16
425					1 (8.33)	4 (33.33)	4 (33.33)	2 (16.67)	1 (8.33)			12
450							1 (20.00)	2 (40.00)	2 (40.00)			5
475										1 (50.00)	1 (50.00)	2
Total	19	32	30	27	13	9	5	4	3	1	1	144

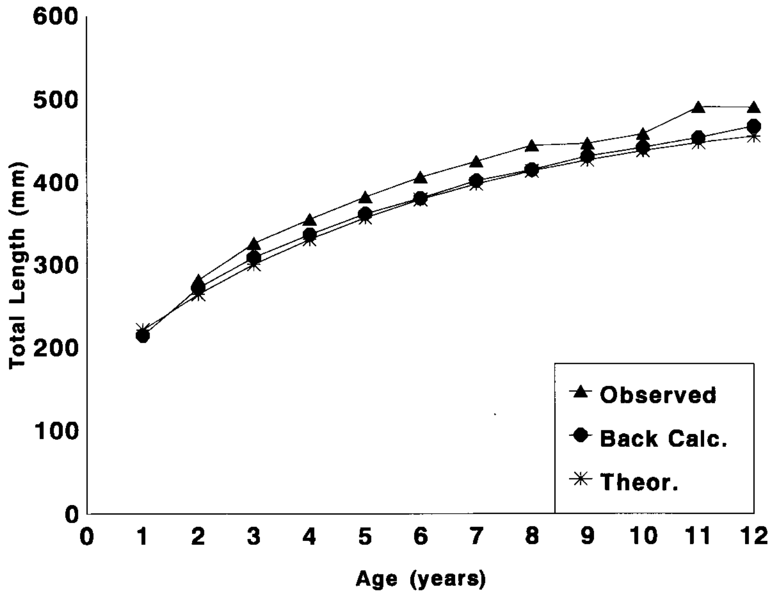

Figure 5. The observed, back-calculates, and theoretical lengths at age for rock hind.

inshore reef fish community currently managed by the South Atlantic Fishery Management Council and, as such, deserve research attention. Although these epinephelines appear to be shorter lived and faster growing than most serranids of the western Atlantic (Manooch, 1987), they present special problems to fishery managers because they are protogynous hermaphrodites (Burnett-Herkes, 1975), and because they are believed to form spawning aggregations which are heavily fished (Shapiro et al., 1993). The condition of growth overfishing for red hind in the Caribbean has been presented by Sadovy and Figuerola (1992). The well documented vulnerability of grouper in general to fishing pressure indicates the need for an assessment of red and rock hind stocks off the southeastern United States.

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